Draft CEC PIER-EA Discussion Paper

Water Resources

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For Discussion at the CEC PIER Technical Meetings on the Climate Change Research Plan Update

California Energy Commission
1516 Ninth Street
Sacramento, CA 95814

August 25, 2008

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Disclaimer

The purpose of this paper is to inform discussions among CEC staff, other state agency staff, non-governmental representatives, representatives of academia and other stakeholders regarding the state of the research on water resources in California. In particular, this discussion paper will identify gaps in our understanding and recommendations for future research initiatives with the end goal of supporting informed and systematic planning for climate change. Note that this discussion paper is **not** a research proposal and does not include recommendations regarding specific research projects.

1.0 Description of Research Topic

Climate change is expected to have a wide range of impacts on California's natural resources, ecosystems, infrastructure, health systems, and the economy. In order to prepare for these challenges, planners must have better information about the risks to vulnerable systems and how effective adaptation can lessen any adverse impacts. Therefore, research under the PIER-EA program is underway to identify potential impacts and effective adaptation methods for California, particularly with regards to energy, ecological resources, water resources, and human health.

Identifying and preparing for climate change impacts to water resources is a key objective of PIER research. Since 2001, PIER has continued to work closely with the California Department of Water Resources (DWR) on water-related research projects. PIER has also informally partnered with the National Oceanic Atmospheric Administration (NOAA). For example, PIER and NOAA jointly fund the California Applications Program (CAP)[1] at Scripps to study climate variability and change in California and Nevada. CAP has played a key role in climate change and water issues in California.

A reliable water supply is critical to agriculture, electric power, industry, households, and natural systems in the state. For example, in the electricity sector, hydroelectric generation represents about 20 % of the electricity generated in the state, and California imports a significant amount of hydropower from the Pacific Northwest. With the additional stresses of a growing population and ongoing development, a better understanding is needed of how hydrological processes will be impacted under all of these changing conditions, which regions or sectors of the economy will be most affected, and what steps can be taken to adapt to these future challenges.

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[1] More information on CAP is available online at: http://meteora.ucsd.edu/cap/

The 2003 Climate Change Research, Development, and Demonstration Plan outlined that PIEREA-sponsored research would address the following policy questions:

- How may climate change and population growth affect California's future water resources, including hydropower production and ecological systems?
- How should the operation of hydropower facilities be improved to be able to cope or benefit under expected significant changes in precipitation levels and the timing of snowmelt in the Sierra Nevada?
- What hydrological variables should be monitored to improve our understanding of the state's natural and managed water systems?

PIER-EA recommended the following short-term research projects to address the questions listed above:

- Monitoring of hydrologically important variables.
- Testing the operation of the state water system under different plausible climate scenarios.

These areas of research were prioritized for support by the PIER program given their relevant importance to California and the limited funds available for climate change research. The research roadmap on water resources (Roos, 2002)[2] also identifies the following priority research items for California:

1. Monitor hydrologically important variables.
2. Test operation of the Central Valley Project and State Water Project system with modified runoff.
3. Model future precipitation.
4. Update depth-duration-frequency rainfall data.
5. Evaluate Golden Gate tide datum.
6. Catalog sea level trends along the coast, in San Francisco Bay and the Delta.
7. Check for recent changes in evapotranspiration.
8. Estimate future changes in evapotranspiration and crop use.
9. Evaluate effect on major multipurpose flood control reservoirs.
10. Model water temperature in major reservoir/river systems.
11. Estimate the effect of climate change on regions adjoining California.

PIER Program and other research to date have begun to address these research priorities. Discussion of this research is described in the sections below.

2.0 Summary of PIER Program Research to Date on Water Resources

As indicated above, PIER-EA research has focused mainly on supporting the measurement of hydrological variables in key parts of the state, and on supporting the

[2] The author of the 2003 roadmap was DWR's chief hydrologist who is a well-known expert on water and climate change issues.

enhancement of the information and models necessary to simulate the water systems in California under a changing climate.

Some of the PIER-EA research reports published on water resources since the 2003 Research Plan include:

- Aircraft Measurement of the Impacts of Pollution Aerosols on Clouds and Precipitation Over the Sierra Nevada (Woodley et al., 2008).
- Monitoring Networks For Long-Term Recharge Change In The Mountains Of California And Nevada: A Meeting Report (Earman and Dettinger, 2008).
- Trends in Snowfall Versus Rainfall for the Western United States, 1949-2001 (Dettinger and Cayan, 2007).
- Integrated Forecasting and Reservoir Management (INFORM) for Northern California: System Development and Initial Demonstration (Hydrologic Research Center, 2007).
- Representing Groundwater in California's Water Management System (Harau and Lund, 2007).
- The Economic Cost of Climate Change Impact on California Water: A Scenario Analysis (Hanemann et al., 2006).
- Economic Impacts of Delta Levee Failure Due to Climate Change: A Scenario Analysis (Hanemann et al., 2006).
- Estimated Impacts of Climate Warming on California Water Availability Under Twelve Future Climate Scenarios (Zhu et al., 2006).
- Climate Change Impacts on High Elevation Hydropower Generation in California's Sierra Nevada: A Case Study in the Upper American River (Vicuña et al., 2005).
- Climate Warming and Water Supply Management in California (Medellin et al., 2005).
- Predictions of Climate Change Impacts on California Water Resources Using CALSIM-II: A Technical Note (Vicuña et al., 2005).
- Economic Impacts of Climate Change on Urban Water Use in California (Dale et al., 2005).
- Climate Change and California Water Resources: A Survey and Summary of the Literature—Second Edition (Kiparsky and Gleick, 2005).
- Climate Change and Water Supply Reliability (Dracup, 2005).

The discussion paper on Regional Climate Monitoring, Analysis, and Modeling lists other related reports on meteorological and hydrological monitoring in key areas of the state. For example, the Scripps Institution of Oceanography and the Desert Research Institute are installing monitoring stations in high elevation areas (e.g., White Mountain) and in remote locations (e.g., Yosemite National Park). The final series of monitoring stations will form a transect from the Central Valley to the Sierra Nevada, and should observe climate change signals predicted by regional climate models, such as differentiated warming where relative temperature changes increase with elevation.

A quick review of the above PIER reports indicates that PIER has contributed to the collection of meteorological and hydrological data in new areas with a specific focus on climate. In addition, significant efforts were made to improve water system models (e.g., CALVIN) to simulate key features for climate change studies, such as underground water resources. PIER has also invested substantial resources to understand the potential effect of particles in the air on precipitation levels in the Sierra Nevada. Preliminary PIER-funded research efforts suggest that particles in the air are reducing precipitation levels in the Sierra Nevada by about 15 percent. These types of studies relate primarily to the topic area of climate monitoring, analysis and modeling, but are mentioned here given their importance to the water system in California. If climate change results in a drying of California, reducing the negative effect of particles on precipitation could become an important adaptation option.

3.0 PIER Accomplishments

Through the PIER Program, researchers have identified several impacts of climate change on the state's hydrological systems. In particular, an earlier start of spring snowmelt, an increase of winter runoff as a fraction of total runoff, an increase in winter flood frequency, and increases in extreme weather event severity and frequency were identified as the major climate change impacts on California's water system. Further, it has been projected that a drier climate may severely affect the economies of rural and agricultural areas, while the urban economies will remain more or less unencumbered. Hydroelectricity supplies were also found to be negatively affected during summer months (e.g., power generation and revenues fall) due to drier hydrologic conditions, though generation in areas with large storage capacity—large reservoirs—are not impacted. Studies also found that pollution aerosols encourage cloud formation in the Sierra Nevada range, which delays the conversion of cloud water into precipitation, thereby causing losses in net rain-volume and reduced stream flow from the western mountain slopes.

With funding from NOAA, CALFED Bay-Delta Program (CALFED), and PIER, the Hydrologic Research Center (HRC) developed the INFORM system to improve the integrated management of five major water reservoirs in Northern California. This project was highly successful, and the INFORM system could be adopted by water agencies responsible for managing these reservoirs in future. PIER funded this demonstration project because a paper released in 2001 by Yao and Georgakakos suggests that improving the management of water reservoirs in California could be an excellent tool to help cope with increase climate variability and change in the future. As described in Section 5.0, the HRC is now testing the INFORM management system to determine its usefulness as an adaptation tool for changes in climate expected at the end of this century.

4.0 Non-PIER Accomplishments in this Area and Opportunities for Collaboration

Substantial work has been done at the national and international level to evaluate climatic impacts, but far less information is available on regional and local impacts. This section will focus on the research addressing the consequences of climate change for water resources and water systems in California.

As part of the PIER program, Kiparsky and Gleick (2005) surveyed and summarized the literature on climate change and California water resources. Other, relevant literature published through 2007 is readily available from the Pacific Institute's Water and Climate Bibliography.[3]

The U.S. Climate Change Science Program (USCCSP) has been funding basic research on the hydrological cycle with a national and global perspective. In addition, the U.S. Environmental Protection Agency (EPA) funded the application of the Water Evaluation and Planning (WEAP) model in California. WEAP is a relatively simple water system simulation model with many advantages, such as the ability of running hundreds of simulations with relatively low computer resource requirements. The National Science Foundation (NSF) has also provided significant funding to RAND Corporation to study the management of the water system under extreme uncertainty. As discussed above, NOAA provides funding for the studies conducted by CAP at Scripps. Finally, CALFED is funding the Computational Assessments of Scenarios of Change for the Delta Ecosystem (CASCADE) study, which is investigating the potential ecological impacts of climate change, in particular sea-level rise, on the Sacramento/San Joaquin Delta region.

The DWR, CAP/Scripps, and PIER "team" is involved in some way in all the non-PIER studies listed above. For example, DWR is using the results of prior work with the WEAP model for further studies that will be part of the climate change section of the next State Water Plan, while PIER is funding an extension of the WEAP model to be able to simulate the western part of the San Joaquin Valley.

The USCCP may start to include more studies on impacts and adaptation options in response to comments received from the National Academy of Sciences (NAS). This would be an important opportunity for California to obtain federal support for its work on impacts and adaptation options for water systems.

5.0 Research Underway/Committed to via PIER Process

The following research projects are ongoing or committed to through the PIER process:

- Performance of the Northern California Water System Under Climate Change: INFORM as an Adaptation Tool (Konstantine Georgakakos, Hydrologic Research Center).
- Water, Energy and Climate Change (John Dracup, UC Berkeley).
- Modeling Integrated Adaptation to Climate Change for California's Water Supply and Hydropower Systems (Jay Lund, UC Davis).
- Contribution of Snowmelt to Underground Water Recharge (PIER RFP/scoring in progress).

NOAA, DWR, and PIER are also planning a major field study to be conducted from October 2009 to April 2010 to examine the effects of aerosols (particles) on precipitation levels, the regional atmospheric energy budget, the effect of black carbon on the

[3] Available online at: http://biblio.pacinst.org/biblio/

reflectivity of snow (albedo), and the physics involved in the formation of atmospheric rivers (NOAA, Air Resources Board (ARB), DWR, and PIER/CEC, 2008).

6.0 Gaps in Research/Knowledge Relevant to California

6.1 Submission from Dr. Jamie Anderson and Dr. Francis Chung, California Department of Water Resources

The PIER-EA program has been successful in supporting research to provide better information and management tools to support decision-making related to water resources under a changing climate. Largely due to the PIER-EA program, DWR has been able to move beyond the qualitative assessment of the climate change impacts to the state's major water resources systems. DWR's 2006 report (DWR, 2006) demonstrates some quantitative analyses, although in a limited scale, that DWR was able to complete. The purpose of this discussion is to identify additional knowledge gaps and to suggest research topics so that further steps can be taken toward the eventual goal of establishing adaptation strategies in water resources planning and management in California.

This paper highlights some key areas where additional work would fill in some of the knowledge gaps and provide broad benefits for water resources management.

Field Data and Understanding Physical Processes

Field observations of climatologic and hydrologic data are needed to improve understanding of California's climate and water resources. Long term data sets are critical for representing the natural variability in California's water resources and to detect long term trends that would indicate climate changes beyond the ranges of historical variability. Thus it is crucial to maintain and enhance existing long term monitoring sites. New field monitoring plans can be developed to expand coverage of existing monitoring programs or to target information on better understanding specific local processes. For example, expanded monitoring could improve understanding of the transition zone between snow covered and rainfall dominated portions of key watersheds. Climate warming is expected to shift the physical location of this transition zone, and other physical processes may also be affected, such as surface water/groundwater interactions (Earman and Dettinger, 2008; Dettinger and Earman, 2007). In addition, the use of new monitoring techniques can continue to improve understanding of physical processes related to climate and water resources. For example, recent research is improving the understanding of snow dynamics in remote mountain areas of the Sierra Nevada by placing relatively small and inexpensive temperature sensors in trees and burying them in the soil (Lundquist, 2008; Lundquist and Cayan, 2007). Remote sensing information provides another avenue for spatial and temporal information related to hydrology, meteorology, and ecosystems (e.g., Johnson et al., 2006). Collecting, interpreting, and incorporating hydrologic and climate observations into management tools is key to reducing knowledge gaps for managing California's water resources under climate change.

Projected Future Conditions

While field monitoring provides insight into the past and present, water resources planning for the future requires projected information on climate, hydrology, water demands, and management practices. Ways to deal with the uncertainties associated with future projections are also needed.

Great advances have been made in archiving global[4] and regional[5] climate change projections and making them available to the public for research and decision making purposes. Continuing to make the latest data from the research community available to decision makers should remain a priority (WGA, 2007). Expanding the number of variables and scenarios available in the archives at finer spatial and temporal scales is important for ecological and hydrologic analyses (C-CAWWG, 2008). Planning processes need to be developed that use information from the projected climate data along with historical representations on climate variability from the paleo-climate and instrumental records (C-CAWWG, 2008).

Although current projection methods provide insight into average future conditions, new methods are needed to better reflect the magnitude and frequency of future extreme events, such as floods. Traditional planning methods for extreme events, such as determining level of safety based on historical return period flood levels (i.e., the 100-year flood) and probable maximum precipitation and probable maximum floods must be evaluated to determine if they are still appropriate under a changing climate. If not, new or modified ways to plan for extreme events must be developed (C-CAWWG, 2008).

Guidance from the research community is also needed to better understand the uncertainties associated with the data, as well as how the data can be used appropriately. For example, should all greenhouse gas (GHG) emissions scenarios be considered equally, or are some scenarios more likely to occur than others? Are some models better than others at representing California's climate (e.g., Brekke et al., 2008)? Do the methods used in refining the course Global Circulation Model (GCM) data to regional scales affect the representation of hydrologically important variables (e.g., Maurer and Hidalgo, 2008)? How should water resource planners interpret broad ranges of projections—for example ranges of projected sea-level rise?

Another area of uncertainty is projections of future water demands. Information is needed on how many people will be in California, where they will be living, and how much water they will use. Likewise, information on projected changes in land use is also needed, such as projections on how much agricultural land will be urbanized and how cropping patterns in the remaining agricultural areas will change. One area of uncertainty is possible effects of climate change on water demands for specific crops. Changes in social values related to water reliability, conservation, flood protection, and environmental management are also unknown (C-CAWWG, 2008).

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[4] Program for Climate Model Diagnosis and Intercomparison (PCMDI): http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

[5] Statistically Downscaled World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (WCRP CMIP3) Climate Projections: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/

Decision Support Tools

Once the research community provides information on possible climate change, methods and tools are needed to help support the use of climate change projections in the decision making process. The PIER-EA program has already supported development, refinement, and application of some of these decision support tools, e.g., WEAP, CALVIN, and CalSim (see Sections 2.0 and 4.0). But new tools and new applications of existing tools are still needed to address the broad range of potential climate change impacts. For example additional tools and analysis methods are needed for assessing impacts of sea-level rise. Another area of interest is the use of decision support tools to develop and explore potential adaptation strategies, such as system re-operation.

Another area of need is an improved understanding of how analysis choices affect the results used in decision making. For example, using the same climate change scenario but different analysis methods and modeling tools can result in different estimates for runoff. An improved understanding of the reasons for these differences, as well as guidance on which methods and tools are most appropriate for a desired type of decision making, are needed.

Adaptation Strategies

In order to prepare for the challenges that climate change poses for water resources management, planners need better information about possible risks and how adaptation strategies can lessen any adverse impacts. Specific adaptation strategies need to be developed that lessen the impacts of climate change and complement other projected changes, such as population growth and shifts in land use. The relative costs, effectiveness, and merits of possible adaptation strategies must be explored. Implementation and evaluation plans for these strategies must be devised. Incremental implementations can be explored that spread the cost and risk over time, and allow for re-evaluation as more information becomes available on how the climate and water resources systems actually evolve.

While adaptation strategies aim to lessen the effects of climate change, mitigation measures attempt to reduce the causes of climate change. Coordination of adaptation and mitigation measures is encouraged (see coordination and management issues section below). Specific recommendations on mitigation measures are beyond the scope of this paper.

Planning Horizons

The typical period length used in the benefit-to-cost analysis in water resources planning is less than 50 years. Benefits or costs beyond this period are inconsequential in the final outcome as they are discounted. The current discount rate used in the California Government analysis is 6 percent. At this rate the present value of a 50-year sequence of annual benefit of $100 is $1,576, whereas the present value of $1,576 in year 50 is $86. Structural and non-structural (operational) measures in adapting to the changing climate require the benefit-to-cost analysis to evaluate cost effectiveness. Projections of temperature or sea-level rise are increasing at a non-linear rate, and the choice of the time frame for these adaptation measures is critical.

Coordination and Management Issues

There are many actions occurring related to adaptation and mitigation at local, regional, and global levels. As a result, there are many opportunities for collaboration and coordination. In the case of adaptation strategies, different sector experts are devising their own plans. Steps should be taken now to improve coordination across various adaptation sectors to maximize the benefits and effectiveness of these strategies. For example, the recent fires in California highlight the linkage between the forestry and water sectors. Extremely dry spring conditions contributed to the large-scale fires throughout California, and in turn, the burn areas will have long-lasting impacts on the watershed characteristics. Other sectors that are linked to water include energy and agriculture.

Another important area for coordination is in the further development and implementation of both adaptation and mitigation measures. Adaptation measures in general are reactive, whereas the mitigation measures tend to be prescriptive. For this reason alone, the planning horizon discussed above should be different for these two types of climate actions. Yet, it is critical for these actions to be integrated and coordinate to accomplish the ultimate goal of successful human response to the changing climate.

Enhanced connections between local, regional, and global climate change management strategies are encouraged. Regional carbon footprints can be helpful in understanding local physical processes related to climate change. Conversely, understanding the consequence of local actions to the regional and global scale will also be useful. The Western Governors' Association (WGA) and other regional actions help establish this connection of information. More deliberate and structured efforts by the PIER-EA program toward this goal are recommended.

6.2 Submission from Dr. Peter H. Gleick, Pacific Institute

A remarkable amount of research on the connections between climate change and water resources has been conducted in California since the early 1980s, when this research effectively began. Indeed, some of the earliest work on integrating climate science and hydrology was done in and for California; as a result, the state is one of the best studied regions, with a wide diversity of efforts. However, many of the areas described in the aforementioned roadmap (see Section 1.0) remain at the center of unanswered questions. In addition, important gaps in research and knowledge relevant to California, and important to water policy makers persist. Below are suggestions for research over the next several years to help fill these gaps.

Monitor hydrologic variables of key importance, particularly precipitation, temperature, snowfall/ water content, runoff, sea-level rise, and evapotranspiration.

The acquisition and analysis of historical and real-time hydrologic data is key to good water management, planning, scenario creation, and climate impact assessment. A set of research efforts to identify new ways of collecting or managing hydrologic variables of interest would be valuable, including remote sensing; new forms of on-the-ground sensors, and new data management methods would be appropriate research objectives.

Model regional-scale changes in climate through both large-scale GCMs and downscaled/regional models.

Large-scale climate models continue to improve and are key to a detailed understanding of regional impacts and consequences. At the same time, improvements in integrating GCMs and regional models are still needed, especially for variables such as precipitation. This topic has been consistently recommended for further research, and we continue to include it here in addition to the ongoing work from Miller et al.

Evaluate science of storm formation and storm tracks in the Pacific, and expand modeling of these climatic characteristics.

Water availability, flood risks, and reservoir operations all depend on the availability of information and forecasts of storm formation, and tracks in the Pacific. Some work is already underway (i.e., Wigley et al.) to improve modeling of these events, but more work is needed in: (a) modeling; and, (b) scenario evaluation of water system vulnerability to different storm conditions.

Intercompare precipitation forecasts from GCMs.

Precipitation details from GCMs remain highly variable, but critical for planning. Model intercomparisons of both results and methods would help reduce uncertainty about precipitation forecasts.

Expand research on impacts of sea-level rise on water-related resources, including effects on coastal aquifers, saltwater intrusion, and saltwater/freshwater marsh ecosystems.

Initial work on sea-level rise is underway in the current grant cycle (e.g., Gleick et al.), but a number of key sea-level rise impacts are not well understood or studied, including effects on coastal aquifers and marsh ecosystems. Coastal/regional water planning will depend on better information on saltwater-intrusion risks. Additional effort is needed to test a wider range of future economic assumptions (scenarios) about development along the coast in order to obtain a clearer sense of economic risks of rising oceans.

Evaluate the implications of changes in the hydrologic system for ecosystems, including rivers, riparian resources, inland and coastal wetlands (including vernal pools), and forests.

More work, perhaps in collaboration with federal and state agencies, is needed to understand the risks of climate change for aquatic ecosystems. The focus should be on impacts representing a cross-section/range of California ecosystems.

Evaluate the implications of changes on groundwater recharge rates, especially in critical basins.

Groundwater is a key component of California's water resources system, but impacts of climate change on both withdrawals and recharge are poorly understood. Specific research focusing on generic types of aquifers or recharge structures is needed.

Evaluate the implications of changes on all water-use demands, including urban, agricultural, and ecosystem.

Some initial work has been done to look at how climate change may affect water use and demands, but this work is only the first step. More detailed end-use assessments are needed to identify key sensitivities—such as outdoor landscape use or evaporative losses—in water-use sectors (e.g., residential, agricultural, industrial, commercial, and institutional).

Evaluate the implications of climate changes for hydroelectric generation, including timing and amount.

A substantial fraction of California electricity—about 20%—is from hydrogenation. Modeling of the effects of climate change for hydropower, including the economic implications of changes in peak/off-peak system generation, is central to better management of both water and energy systems statewide.

Evaluate the economic implications of climate impacts on California water systems.

All assessments conducted to date would benefit from better assessment of the economic costs and benefits of climate impacts.

Expand testing of the operation of state and federal water systems for changes in both water availability and operating rules/ systems.

More detailed assessments of the role of operations, operating rules, water rights, and delivery schedules are needed to better understand the strengths and weaknesses of water management in the context of climate change. No major infrastructure should be built without including the long-term effects of climate on economics and water management. This research area expands on ongoing work from Georgakakos and the HRC.

Review the advantages and disadvantages of existing water policies in helping to adapt to climate changes.

A wide range of water management strategies, technologies, and economic approaches may be useful for adapting to climate change, but little research has been done to test these under different conditions.

Explore the use of economic tools as adaptation strategies.

Economics, in the forms of water prices, subsidies, tax policy, and more, is very influential in determining ability to adapt to climate change. More effort is needed to integrate economics into analysis tools.

7.0 Conclusions and Prioritized Recommendations

7.1 Submission from Dr. Jamie Anderson and Dr. Francis Chung, California Department of Water Resources

The PIER-EA research program is encouraged to continue supporting the measurement of hydrological variables in key parts of the state, and the enhancement of the information and models necessary to simulate the water systems in California under a changing climate. Future research needs are prioritized below for each category above. The categories themselves are not prioritized relative to each other.

Field Data and Understanding Physical Processes

- Jointly monitor sea levels and vertical land movement of coastal and estuarine areas; for example, jointly monitor sea levels in the Bay-Delta system, and subsidence of Delta islands.
- Add or enhance monitoring sites to improve understanding of physical processes related to water resources that may be affected by climate change, such as:

- Changes in the transition zone between snow-covered and rain-dominated portions of key watersheds.
- Relationship between snow pack and groundwater recharge.
- Effects of land-cover and ecosystem responses to climate change on precipitation-runoff relationships.
- Enhance observations of high-elevation processes.

– Explore uses of satellite data (e.g., GRACE or MODIS) to applications useful to water resources management, and to monitor potential changes induced by climate change.

– Investigate uses of new monitoring technologies, such as inexpensive temperature sensors, that can be used to collect data in sites that are not amenable to traditional monitor techniques, such as a tower of sensors.

– Encourage a National Research Council (NRC) or similar science review of sea-level rise issues, with a focus that includes review of adequacy of coastal mapping (basic geodetic as well as flood hazard/floodplain).

Projected Future Conditions

– Guidance is needed from climate change researchers to better understand the uncertainties associated with climate change projections:

  - Relative likelihoods of future GHG emissions scenarios.
  - Ability of different GCMs to represent California's climate.
  - Uncertainties in sea-level rise projections and their associated assumptions.
  - How uncertainties are related to each other (e.g., is there a compounding effect or a mitigating effect?).

– Encourage researchers to work with decision makers to determine guidelines for appropriate uses of climate change data.

– Create or enhance existing archive of climate change data to include information at spatial and temporal scales needed for decision making; increase the number of variables available in these archives.

– Investigate whether the statistical properties related to water-resources variables, such as precipitation variability, will remain the same under a changing climate (stationarity) or whether these statistical properties will change (non-stationarity). This is especially important for assessing impacts of extreme events such as flooding or drought.

– Improve demographic forecasting tools and provide more information to decision makers on the uncertainties associated with demographic projections, such as population and land use.

– Develop methods for simulating climate change at finer spatial and temporal resolutions as an alternative to current downscaling methods.

- Develop a dynamical downscaling technique for the State. Develop and apply a meso-scale model (i.e., MM5) or Weather Research and Forecasting (WRF) Model for California, and archive the data for public dissemination.
- Investigate crop water demand changes under a changing climate.
- Project changes in cropping patterns (e.g., type of crop, amount of land in farm production) under climate change.

Decision Support Tools

- Continue to promote communications and collaboration between climate change researchers and water resource decision makers through conferences and workshops.
- Develop and enhance tools to assess potential impacts of sea-level rise on coastal areas and the Sacramento-San Joaquin Delta.
- Develop guidelines for assessing impacts of extreme events under climate change, such as flooding; assess risks of extreme events for dam and levee safety.
- Develop guidelines for decision support processes after investigating how various analysis choices effect the final information provided for decision making; e.g., how does choice of downscaling method affect runoff estimations?
- Develop methods to jointly incorporate paleo-climate, instrumental measurements, and projected climate into the planning process.

Adaptation Strategies

- Integrate and coordinate mitigation and adaptation measures.
- Develop adaptation strategies and ways to determine trade-offs that consider competing needs for water supply, flood control, environmental protection, water quality, hydropower, and recreation, and the possible impacts to each area from climate change.
- Develop tools and methods for assessing possible re-operation of existing or projected future water resources systems to reduce the impacts of climate change; assess the risks associated with these adaptive strategies. Strategies could include: combinations of operations, regulatory, and structural changes, such as changing traditional flood control rules; enhancing conjunctive use of surface and groundwater; expanded water banking; exploring alternative water sources; and conveyance and storage.
- Develop adaptation strategies for sea level rise impacts on coastal areas and the Sacramento-San Joaquin Delta.
- Explore ways to incorporate adaptation into planning processes.

Other Management Issues

- Investigate a proper length of planning horizon for various sector adaptation plans.

- Develop statewide methods and guidelines for incorporating climate change into Integrated Regional Water Resources Management Plans (region to region and statewide).
- Begin projects that will facilitate cross-sector coordination and integration.
- Develop linkage between local, regional, and global scale actions, and their consequences.

7.2 Submission from Dr. Peter H. Gleick, Pacific Institute

[To be provided.]

Acknowledgements

Jamie Anderson and Francis Chung would like to thank Mike Anderson (DWR) and Levi Brekke (Reclamation) for their assistance with this paper.

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